Towards Left-handed Metamaterials at Optical Frequencies

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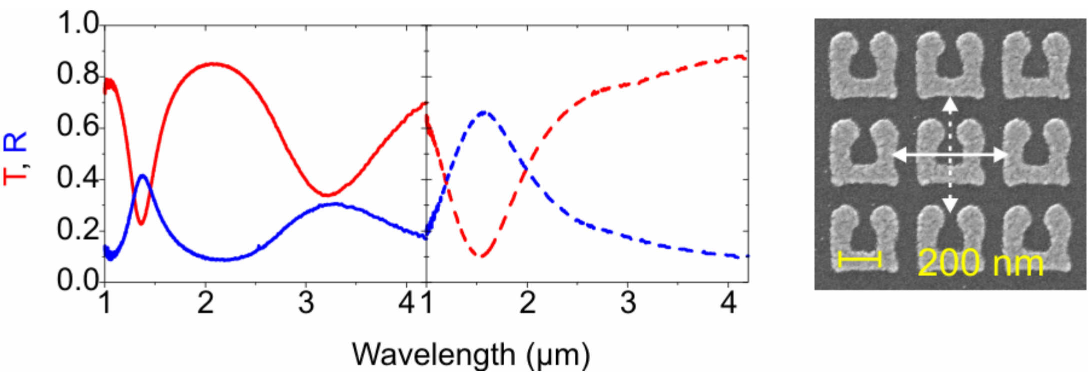
Metamaterials allow for optical properties not available from natural materials. An important application are left-handed metamaterials which exhibit a negative index of refraction. A prerequisite for this unusual property is that the effective permittivity ε and the effective permeability µ are both negative. While a negative ε is not unusual, a large magnetic response, in general, and a negative µ at optical frequencies, in particular, does not occur in natural materials. In metamaterials, this crucial aspect is achieved by mimicking an LC-oscillator, consisting of a magnetic coil and a capacitor. Such metamaterials were first realized at frequencies around 10 GHz (3-cm wavelengths) [1]. Using nanofabrication techniques, we increase the LC-resonance frequency to about 100 THz (3-µm wavelength) [2], bringing a negative index of refraction at optical frequencies into reach. Transmission (T) and reflection (R) spectra for two orthogonal linear polarizations (as indicated in the SEM image) are shown below. For normal incidence, coupling to the LC resonance is only possible if the electric field has a component normal to the plates of the capacitance (LHS). The features around 3-µm wavelength correspond to the LC-resonance. The resonance completely disappears if the electric field vector is rotated by 90° (RHS). The plasmon resonance at 1.5-µm wavelength can be excited in both configurations [2]. More recently, we have achieved a magnetic response at telecommunication wavelengths.



[1] R. A. Shelby et al., *Science*, **292**, 77 (2001).
[2] S. Linden et al., *Science*, **303**, 1494 (2004).